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Application of Analytic Hierarchy Process and Structural Equation Modeling for Supporting the Decision-Making of Shuttering Preference in Construction Projects

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ABSTRACT

Shuttering is a temporary mold or structure into which concrete is poured and shaped. The choice of formwork can significantly impact the construction process, timeline, cost, and quality of the final structure. Certainly, identifying the most important criteria for selecting formwork (shuttering) is a valuable endeavor for supporting contractors in making informed decisions. This study is motivated by using the Analytic Hierarchy Process (AHP) to assess shuttering alternatives based on the identified evaluation criteria from the prior factor analysis stage. In addition, the Structural Equation Modelling (SEM) approach is employed to discover underlying relations between the latent factors of the model base on using a combination of statistical data and qualitative causal assumptions. The study reveals that plastic shuttering as the optimal solution according to expert evaluations and verified the hypothetical causal relations among the latent variables. The study's outcomes are intended to enhance managers' understanding of shuttering systems, promoting the adoption of decision support tools in construction projects for improved planning accuracy and project success.

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1. Introduction

Along with the development of the economy, high-rise buildings have now become symbols of modernity and prosperity in major cities worldwide. High-rise and super-tall structures have been rapidly developing in many countries across continents. High-rise construction projects demonstrate excellence in shaping the urban landscape and city highlights; they showcase the capacity to accommodate various human activities with different functions; they reflect architectural creativity, advancements in construction technology, and the exploration and use of new building materials. Additionally, the remarkable growth of urban areas and the migration of people from rural regions to large cities for education and employment create pressure on land use, contributing to the increase in the number of tall buildings globally [1,2].

The cost of constructing a high-rise building is influenced by various factors, and the choice of a shuttering system is indeed one of them. Shuttering, also known as formwork, is a temporary mold into which concrete is poured and allowed to harden. The type of shuttering system used can impact construction speed, quality, and ultimately, the overall project cost [1,3]. In addition, the rapid urbanization in developing countries, characterized by a strong influx of people into major cities, poses significant challenges related to housing, workplaces, and infrastructure. The increasing concentration of population in urban areas has led to a surge in demand for residential and commercial spaces, resulting in a strain on available land and infrastructure systems. The development of tall buildings is frequently regarded as an essential resolution for vertical urban growth in addressing these challenges [1,2]. It appears that you are discussing the safety considerations related to construction processes, specifically mentioning the risk of damage to structures due to shuttering collapse. The collapse of shuttering can indeed pose significant risks to the safety of workers, cause injuries, and result in damage to resources [4]. If shuttering activities are being assessed as high-risk and particularly dangerous for construction workers, it's crucial to address these concerns to ensure the safety and well-being of the workers and the success of the construction project [5,6].

Moreover, selecting the right shuttering system for high-rise building construction is a crucial decision that can significantly impact the overall success of the project. Various factors should be thoroughly considered and evaluated to ensure the chosen system aligns with the project requirements and goals [7]. Certainly, selecting the right shuttering system for construction projects is a crucial aspect of the construction process.

The choice of shuttering system depends on various factors, including the local climate, construction requirements, budget constraints, and the type of structure being built. Selecting the appropriate shuttering system for high-rise building construction is indeed a crucial decision that involves the collaboration of various stakeholders. The shuttering system, also known as formwork or molds, is a temporary structure used to support and contain concrete during the curing process until it reaches sufficient strength to support its own weight [8]. Hence, selecting the right shuttering system for a construction project is indeed a critical task that requires careful consideration. The choice of the shuttering system can significantly impact the efficiency, cost, and safety of the construction process.

Currently, in the selection of shuttering, construction units are increasingly paying attention to all three main factors: quality, safety, and economy. However, the traditional wooden shuttering system can only address the economic aspects of shuttering construction for medium and small-scale projects. Therefore, it is gradually being replaced by more modern shuttering systems to save time, reduce costs, improve project quality, and better align with the characteristics of the current trend in the development of construction projects. Table 1 presented below displays the pertinent studies regarding the selection of shuttering.

Table 1
Synthesis of some relevant previous studies.

No	Author (Year)	Paper	Contribution	Methodology	Limitation
1	Terzioglu, T., Polat, G., Turkoglu, H. (2022)	Formwork system selection criteria of buiding construction projects: A structual equation modelling approach [7]	Quantify the criteria groups for selecting shuttering systems and investigate their impacts. The study results confirm that the characteristics of shuttering systems are influenced by structural design and local conditions. Additionally, shuttering system features significantly affect project costs and efficiency indices. The research contributes significantly to the knowledge related to shuttering selection criteria, serving as a guide for structural experts involved in the shuttering selection decision-making process. Furthermore, the study findings can be used to enhance project performance factors.	Collect data using survey questionnaires. The analysis method used to determine the criteria groups combined with descriptive statistical methods. Structural Equation Modeling (SEM) approach used to quantify and identify the effects among latent factors.	Data collected in the study were limited to the construction industry in Turkey, requiring careful consideration and validation before applying the research results in other countries. Criteria for selecting shuttering systems were identified and examined in relation to building construction projects; nevertheless, the selection of shuttering may differ based on the specific characteristics of the project being implemented.
2	Sowndharya, A., Vidhya, A (2022)	Analyising advanced formwork system for high rise building construction [1]	Identify factors to consider in shuttering selection by analyzing and comparing specific 6 types of advanced shuttering used in high-rise building projects and their technological advancements. Draw conclusions about the suitable and efficient shuttering for high-rise construction and assess feasibility for each specific project.	Collect data from journals and published books to generalize knowledge, list impacts. Use the Decision-Making Model (DMM) to select suitable advanced shuttering systems for specific types of high-rise buildings.	Specific statistical indicators proving the suitability of each type of advanced shuttering for each specific building height range have not been clearly presented.
3	Rajeshkumar, V., Anandaraj, S., Kavinkumar, V., Elango, K. S. (2021).	Analysis of factors influencing formwork material selection in construction buildings [9]	The study identified and ranked key factors influencing the selection of shuttering systems in high-rise buildings, including work accessibility, quality, surface finish, shuttering preservation, capital costs, safety, structural arrangement, lifespan, adaptability to the environment, and labor costs. Additionally, the study correlated 40 identified factors, categorizing them into 5 impact aspects, providing a broader understanding of shuttering selection.	Survey questionnaire method Descriptive statistics to rank impacts Factor analysis method.	The study conducted surveys in Tamilnadu, India, limiting the research scope and suggesting careful consideration when applying results in areas with different policy, social, environmental characteristics, etc.

4	Xiao, Y. (2021)	The importance of formwork methods in the economical execution of concrete structures [10]	Analyze the economic and technical aspects of common shuttering types. Demonstrate conditions and limitations of using a suitable shuttering system in typical local situations. Discuss the selection of high-rise shuttering and analyze the rationality of the selection.	Analysis and comparison method.	Limit to concrete structure only.
5	Pawar, A. D., Rajput, B. L., & Agarwal, A. L. (2018)	Factors affecting selection of concrete structure formwork [11]	Compare factors, including cost, quality, cycle time, repetition frequency, and safety impact on the selection of shuttering among three types: traditional, Mivan, and Doka. The study affirms that the initial cost of shuttering is a crucial criterion influencing the selection.	Collect data through survey questionnaires. Analyze data using the Relative Importance Index (RII).	Limit to concrete structure only.
6	Kumar, H., Kavitha, K., Vishwas, G. R. (2017)	Comparison study aluminum and conventional formwork technology [12]	Study the technology of aluminum shuttering production and compare it with conventional shuttering based on cost, time cycle, and concrete used in mold processing.	Collect data and compare.	Limit to aluminum shuttering only.
7	Abou Ibrahim, H. A., Hamzeh, F. R. (2015)	Role of formwork systems in high-rise construction [13]	Emphasize the importance of advanced high-rise shuttering in streamlining concrete work processes, allocating resources more efficiently, reducing waste, minimizing inventory, and providing a safer working environment. Additionally, the study outlines factors influencing sequence and pace concerning the schedule of advanced shuttering.	Compare advanced shuttering systems and conventional shuttering. Use a process model to describe construction activities and their interdependencies for both cases.	Development research is based on the synthesis of knowledge from previous relevant studies without a realistic assessment of suitability for each specific region or project type.

This research has consolidated and augmented the thirty-three specific factors impacting the choice of shuttering in the context of high-rise building construction. Moreover, interviews with experts revealed additional factors such as the tightness of shuttering, the requirement for assembly skills of workers, and recyclability. Analytic Hierarchy Process (AHP) model is utilized for the selection of shuttering options based on expert interviews. Significantly, the study introduces plastic shuttering as an option in the comparative calculation model, a material not previously considered in earlier studies.

After conducting the analysis, the shuttering systems have advantages in the order of plastic shuttering, aluminium shuttering, timber shuttering. In this context, the plastic shuttering option with the highest overall aggregate weight is deemed the most favourable choice, as assessed by the expert panel through a pairwise comparison of all criteria using the established AHP model. Subsequently, the research offers a comprehensive understanding of shuttering-related activities in the construction projects, serving to aid construction enterprises in efficient planning, cost management, progress monitoring, and overall project quality enhancement.

2. Model development

In the Qualitative Analysis phase, based on previous studies both domestically and internationally, the research will identify a set of criteria affecting the decision to choose

shuttering in the civil engineering projects in Vietnam throughout the project implementation stages. This set of factors forms the basis for designing a preliminary survey questionnaire for the study. Subsequently, a pilot test, a preliminary survey, is conducted to gather experts' opinions on the preliminary survey questionnaire. From there, a comprehensive survey questionnaire is formed to collect data for the study [2,14–16].

In the Quantitative Analysis phase, the research analyzes the collected data, including respondents' information through the survey process. The study will conduct the Exploratory Factor Analysis (EFA) to discover latent factors influencing shuttering selection decisions in high-rise construction. Applying the Analytical Hierarchy Process methodology, a decision support model will be formulated for shuttering alternative, discussing the analysis results, and proposing suitable selection options. The study will clarify the differences in evaluating the impact factors of shuttering selection decisions in high-rise projects among stakeholders in different project stages.

The Analytical Hierarchy Process (AHP) is a hierarchical analysis method designed to address complex multi-criteria decision-making issues. AHP allows decision-makers to synthesize the knowledge of experts on the research problem, combining both objective and subjective data within a logical hierarchy. AHP provides decision-makers with an intuitive approach using conventional judgment to assess the importance of each component through pairwise comparisons. AHP integrates both qualitative and quantitative aspects of human thinking: qualitative through ordinal ranking and quantitative through the resulting weight set for each ranked factor.

AHP is based on three principles: problem analysis (establishing hierarchy), comparative evaluation of components (pairwise comparisons between factors) and synthesis of priority levels (determining weight matrices). The AHP model analysis procedure is performed in the following steps:

Step 1: Analyze the problem and identify the required solution.

Step 2: Identify the factors to use and construct a hierarchy tree of factors.

Step 3: Conduct expert surveys to gather opinions on priority levels.

Step 4: Establish pairwise comparison matrices.

Step 5: Calculate weights for each level and each group of factors.

Step 6: Calculate the Consistency Ratio (CR). The CR must be less than or equal to 10%. If it is greater, repeat steps 3, 4, 5.

Step 7: Repeat steps 3, 4, 5, 6 for all levels and groups of factors in the hierarchy tree.

Step 8: Calculate the synthesized weight and make observations.

Structural Equation Modeling (SEM) is a powerful and versatile statistical method widely used in social sciences, economics, psychology, and other fields to analyze complex relationships among variables. SEM goes beyond traditional statistical techniques by simultaneously

examining the interrelationships between observed and latent variables within a comprehensive framework. The key features and components of the SEM approach is described in Figure 1.

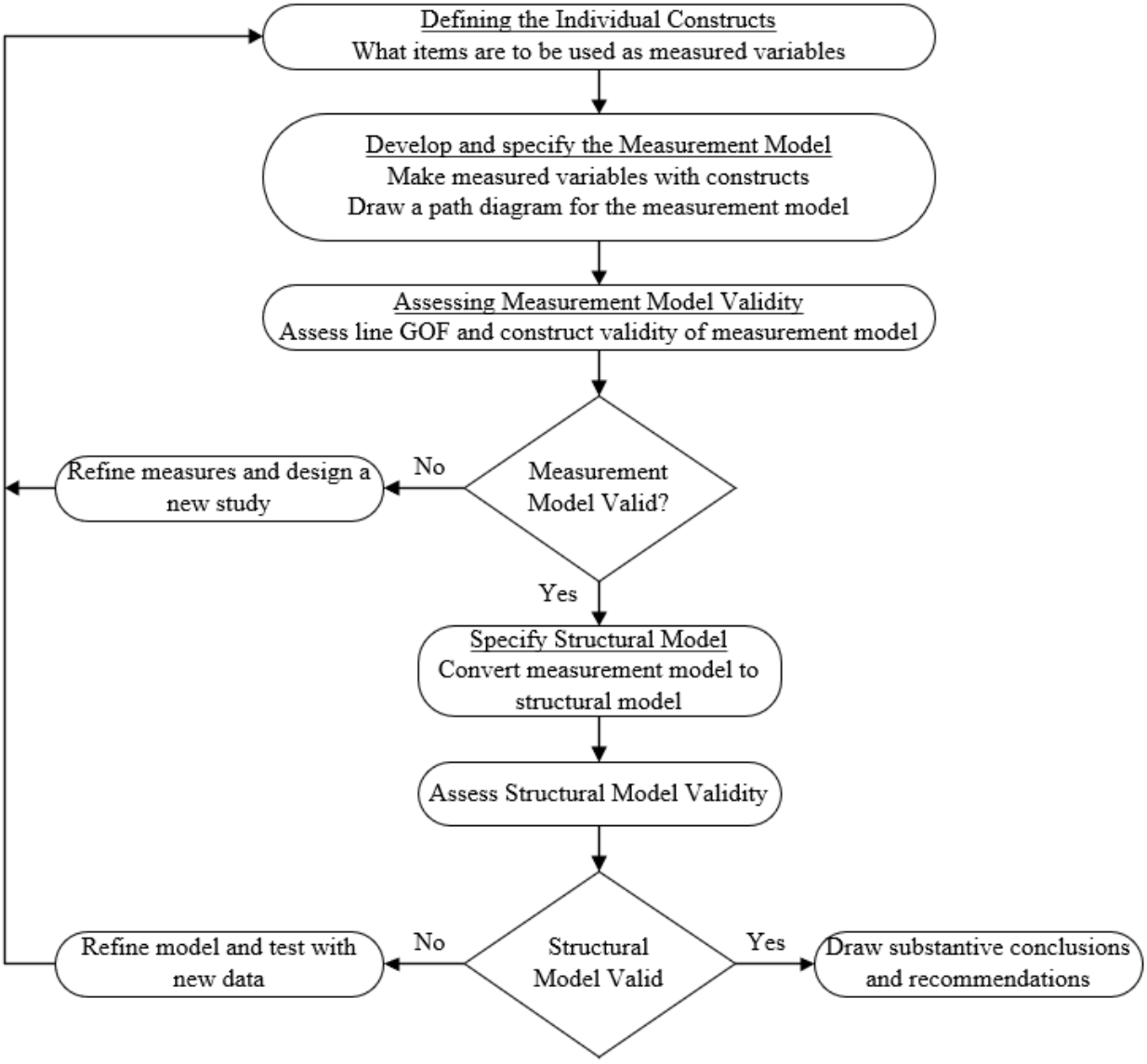
Defining the Individual Constructs
What items are to be used as measured variables
Develop and specify the Measurement Model
Make measured variables with constructs
Draw a path diagram for the measurement model
Assessing Measurement Model Validity
Assess line GOF and construct validity of measurement model
Measurement Model Valid?
No
Refine measures and design a new study
Yes
Specify Structural Model
Convert measurement model to structural model
Assess Structural Model Validity
Structural Model Valid
No
Refine model and test with new data
Yes
Draw substantive conclusions and recommendations

Fig. 1. SEM procedure.

Variables:

Observed Variables: These are directly measured or observed in the study.

Latent Variables: These are unobservable or underlying constructs that are inferred from observed variables. Latent variables are often used to represent complex concepts that cannot be directly measured.

Path Diagram:

SEM uses a path diagram to visually represent the hypothesized relationships between variables. Paths between variables indicate the direction and strength of the relationships.

Equations:

SEM involves a system of equations to describe the relationships between variables. These equations capture both the observed and latent variables and their interconnections.

Model Fit Indices:

SEM assesses how well the proposed model fits the observed data using various fit indices. Common fit indices include the Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR).

Covariance Structure:

SEM allows the modeling of the covariance structure, accounting for the relationships and dependencies among variables. It can handle multiple dependent variables and account for measurement errors.

Confirmatory Factor Analysis (CFA):

A subset of SEM, CFA is often employed to assess the goodness-of-fit of the measurement model, evaluating how well latent variables represent the observed variables.

Path Analysis:

SEM allows for the estimation and testing of direct and indirect paths between variables. This enables researchers to explore complex causal relationships.

Model Modification:

SEM is valuable for testing complex theoretical models, evaluating hypotheses, and examining the underlying structure of relationships among variables. It provides a comprehensive and flexible framework for researchers to explore and understand the intricate dynamics within their data.

Questionnaires serve as valuable instruments for gathering data, enabling researchers to explore relationships, trends, and patterns. Designing an effective questionnaire requires careful consideration of various factors to ensure the accuracy and relevance of the collected information.

To achieve the objective of the study, two survey questionnaires were conducted to collect views from individuals and experts operating in the construction field. Designing the first survey questionnaire based on the review of previous domestic and foreign relevant documents and studies to collect influencing factors and present them in the preliminary survey questionnaire. The flowchart of the research procedure is shown in Figure 2.

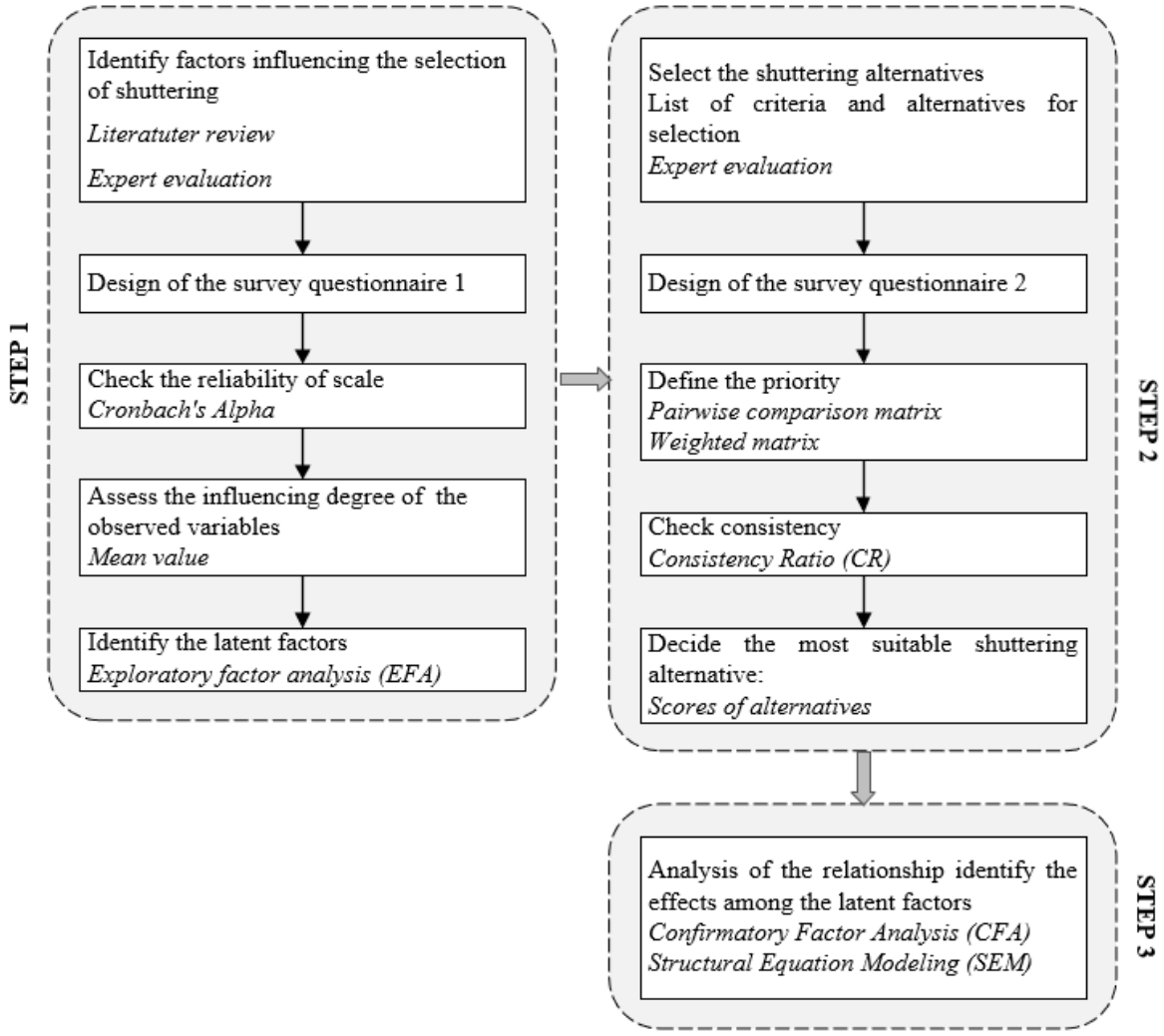
STEP 1
Identify factors influencing the selection of shuttering
Literatuter review
Expert evaluation
Design of the survey questionnaire 1
Check the reliability of scale
Cronbach's Alpha
Assess the influencing degree of the observed variables
Mean value
Identify the latent factors
Exploratory factor analysis (EFA)
STEP 2
Select the shuttering alternatives
List of criteria and alternatives for selection
Expert evaluation
Design of the survey questionnaire 2
Define the priority
Pairwise comparison matrix
Weighted matrix
Check consistency
Consistency Ratio (CR)
Decide the most suitable shuttering alternative:
Scores of alternatives
STEP 3
Analysis of the relationship identify the effects among the latent factors
Confirmatory Factor Analysis (CFA)
Structural Equation Modeling (SEM)

Fig. 2. Flowchart of the research steps.

3. Case study

The questionnaires were designed to collect information relevant to the importance of the criteria shuttering criteria selection. A total of 300 experts in Vietnam were invited to evaluate relative weights of questions based on their practical experience. Their answers were subsequently statistically analyzed. To reduce the influence of extreme values, the trimmed sample mean method was used. By sorting the weighted data, the upper and lower 10% of the data were excluded from the calculations of the weighted means. Finally, 250 valid responses, which were used to calculate the reliability were obtained.

3.1. Analysis results of influencing factor groups

The initial set of factors comprises 8 variables (CP1, CP2, CP10, CP11, CP12, CP13, CP14, CP15) with factor loadings ranging from 0.577 to 0.817. These variables exhibit similarities

pertaining to the attributes of the shuttering system, contributing to heightened labor efficiency and an elevation in worker safety.

Table 2
Group of factors influencing to the selection of shuttering in the high-rise building construction.

Coding	List of factors	Factor loading					
		1	2	3	4	5	6
I	Labor productivity						
CP11	Construction speed [4,17]	0.817					
CP12	Require assembly skills of workers [Expert opinion]	0.781					
CP2	Shuttering quality [18]	0.771					
CP10	Conformity with structures [19,20]	0.725					
CP15	Eco-friendly materials [Expert opinion]	0.719					
CP14	Construction productivity [4]	0.611					
CP1	Shuttering materials (metal, wood, plastic, etc.) [18]	0.601					
CP13	Safety in construction [20]	0.577					
II	Economic efficiency						
CO3	Transportation costs [4,20]		0.779				
CO4	Maintenance and preservation costs [4,20]		0.748				
CO2	Installation costs [20]		0.725				
CO5	Revenue after liquidation or sale of scrap [Expert opinion]		0.652				
CO1	Initial investment costs (purchase or lease) [8,17,19]		0.603				
III	Project characteristics						
DA3	Floor structure plan [21,22]			0.835			
DA4	Total number of floors and floor height [4,9,23]			0.758			
DA2	Building shape [8]			0.740			
DA1	Project completion time [20]			0.648			
IV	Working ability						
CP5	Shuttering tightness [Expert opinion]				0.862		
CP4	Load capacity [4,24]				0.755		
CP7	Flexibility, high compatibility [17,24]				0.642		
V	Available equipment						
DA8	Minimize the burden on transportation equipment by using advanced shuttering system [22]					0.805	
DA7	Compatibility with construction machinery and equipment available on construction site [17]					0.800	
DA6	Available shuttering [20]					0.748	
VI	Environmental conditions						
MT1	Weather and ambient conditions [21]						0.777
MT2	Site conditions, yard size suitable for construction [3,21]						0.768
MT3	Methods of storage, handling and preservation [9,20]						0.707

Therefore, the factor is named “Labor productivity”. The quality of the shuttering system is reflected in the precision of the molded member, encompassing aspects like shape, dimensions,

structure, and surface finish. The second set of factors includes 5 variables (CO1, CO2, CO3, CO4, CO5) with factor loadings from 0.603 to 0.779. These variables pertain to the costs associated with shuttering usage and the system's residual value. The factor is named “Economic efficiency”. The allocation of the initial budget for purchasing or leasing, labor costs, and transportation costs are crucial considerations. Traditional shuttering systems may not be cost-efficient for large-scale projects due to increased labor requirements. The third group of factors encompasses 4 variables (DA1, DA2, DA3, DA4) with factor loadings from 0.648 to 0.835. These variables pertain to the architecture features, dimensions and construction pace, collectively constituting the factor labeled as "Project characteristics.". High-rise project construction speed depends on factors like shuttering erection and dismantling time. The fourth set of factors includes 3 variables (CP4, CP5, CP7) with factor loadings from 0.642 to 0.862. These variables address the workability and flexibility of the shuttering system to meet engineering design requirements. The factor is named “Working ability”. A quality shuttering system must be strong enough to bear all construction loads, providing a safe working environment. The fifth group of factors includes 3 variables (DA6, DA7, DA8) with factor loadings from 0.748 to 0.805. These variables are associated with optimizing the operational capacity of the resources available on the site, forming the factor “Available equipment”. The last group factors comprise 3 variables (MT1, MT2, MT3) with factor loadings from 0.707 to 0.777, addressing ambient conditions and storage areas. The factor is named “Environmental conditions”. Weather factors, temperature variations, area near the sea are also directly influence shuttering selection (see Table 2).

3.2. Analysis results of AHP model

The AHP is a decision-making method that helps prioritize and select the best option from a set of alternatives. In the context of choosing between three options for shuttering (timber, aluminum, and plastic). In addition, from EFA analysis results, the study has identified 6 criteria to consider and evaluate when deciding to select shuttering and build an analytical model (see Figure 3).

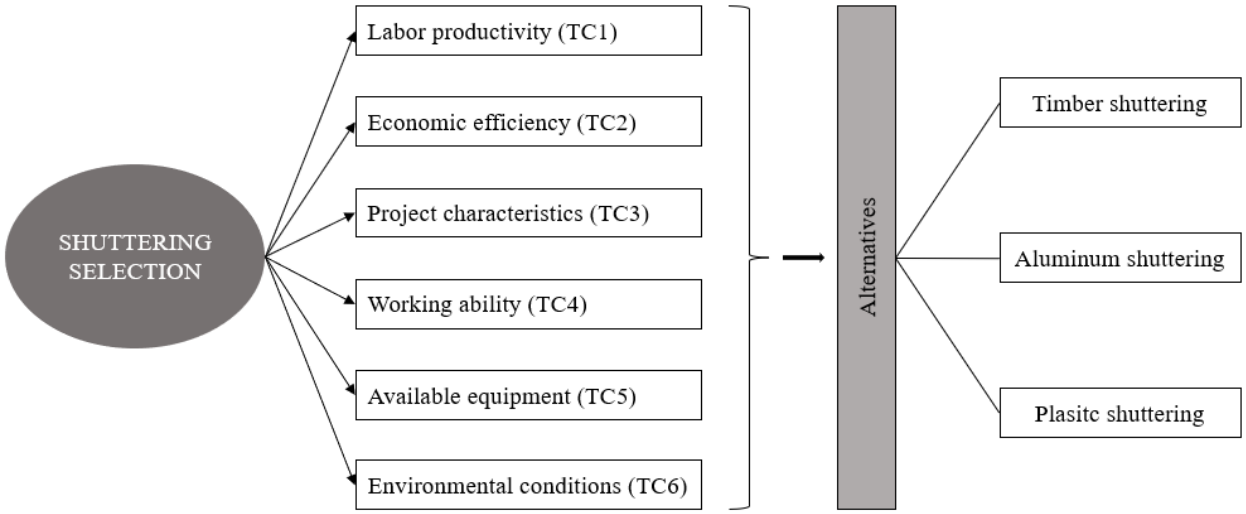

Fig. 3. AHP model to select shuttering alternatives in construction projects.

For each criterion, compare the importance of one criterion relative to another, assigning a numerical value based on the scale of importance (1 to 9) as shown in Table 3. Determine the alternatives' weights based on each criterion, prioritizing alternative options according to individual criteria and assess the consistency ratio. Researchers constructed matrices specific to each criterion, each with a size corresponding to the number of options. Given the existence of six comparison criteria, a total of six matrices must be computed. The aggregate results are shown in Table 4 and 5.

Table 3
Summary of priority evaluation among pairs of criteria according to expert opinion.

Criteria	TC1	TC2	TC3	TC4	TC5	TC6
TC1	1.000 (0.525)	4.714 (0.244)	4.714 (0.718)	5.143 (0.483)	6.714 (0.381)	7.286 (0.222)
TC2	0.212 (0.111)	1.000 (0.052)	0.215 (0.033)	0.263 (0.025)	0.199 (0.011)	6.571 (0.200)
TC3	0.212 (0.111)	4.641 (0.240)	1.000 (0.152)	3.857 (0.362)	4.571 (0.259)	6.286 (0.191)
TC4	0.194 (0.102)	3.798 (0.196)	0.259 (0.039)	1.000 (0.094)	5.000 (0.283)	5.429 (0.165)
TC5	0.149 (0.078)	5.030 (0.260)	0.219 (0.033)	0.200 (0.019)	1.000 (0.057)	6.286 (0.191)
TC6	0.137 (0.072)	0.152 (0.008)	0.159 (0.024)	0.184 (0.017)	0.159 (0.009)	1.000 (0.030)
Weight	0.429	0.072	0.219	0.147	0.106	0.027

Table 4
Summary of calculation results.

	TC1	TC2	TC3	TC4	TC5	TC6
Timber	0.082	0.088	0.093	0.080	0.085	0.372
Aluminum	0.421	0.492	0.446	0.389	0.425	0.469
Plastic	0.497	0.420	0.461	0.531	0.490	0.159

Table 5
Weight results of shuttering selection alternatives.

Timber	0.093
Aluminum	0.429
Plastic	0.479

3.3. Results of the hypotheses model and SEM approach

The SEM is synthesized to check hypotheses mentioned in the prior part. SEM will present main links among constructs of the model. There are a total of five linkages as shown in Figure 4. The coefficients between two constructs will discover their relationship. At first, a conceptual framework was formulated to depict the connections among the six groupings of shuttering selection criteria, derived from the outcomes of the EFA and the CFA. Figure 5 illustrates this conceptual framework, and the subsequent hypotheses are established within the framework.

Based on exploratory factor analysis result, the proposed structural model and hypotheses were specified as shown in Figure 6 and 7. There are five path diagrams of structural equation model, with five hypotheses respectively:

H1. "Project characteristics" has a direct positive relationship and significant effect on "Working ability".

H2. "Available equipment" has a direct positive relationship and significant effect on "Working ability".

H3. "Environmental conditions" has a direct positive relationship and significant effect on "Working ability".

H4. "Working ability" has a direct positive relationship and significant effect on "Labor productivity".

H5. "Working ability" has a direct positive relationship and significant effect on "Economic efficiency".

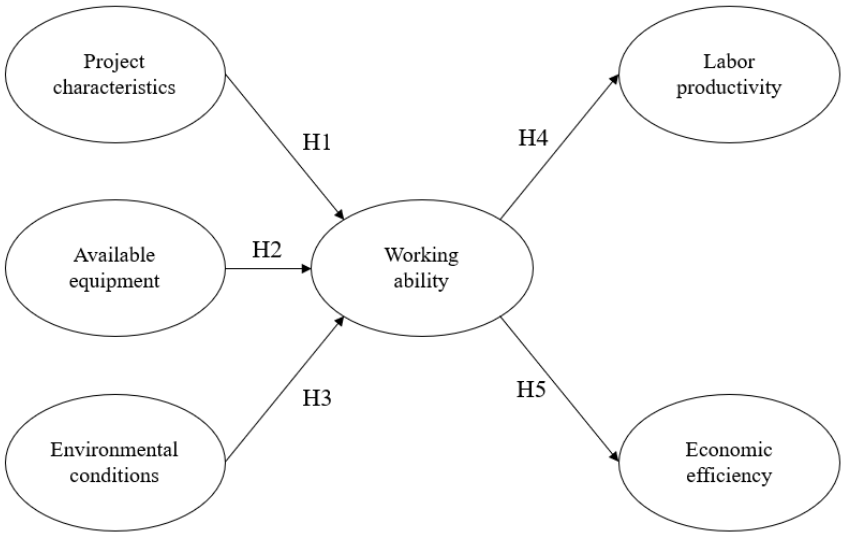

Fig. 4. Hypothesis model for shuttering selection in construction projects.

In this phase, the research objectives are achieved by developing a measurement model and a structural model in SEM with the support of SPSS (version 26.0) and AMOS (version 24.0) software. The analysis encompassed six latent factors (the main factors determined from the EFA step) and 26 observed variables.

The measurement model enables the estimation of relationships between latent and observable variables, a validation conducted through the CFA. Subsequently, the structural model implemented from the conceptual framework was analyzed with the goal to explain the causal dependencies among the latent variables, in which project characteristics (TC3), available equipment (TC5), and environmental conditions (TC6) served as exogenous latent factors, while working ability (TC4), labor productivity (TC1), and economic efficiency (TC2) indicators operated as endogenous latent factors.

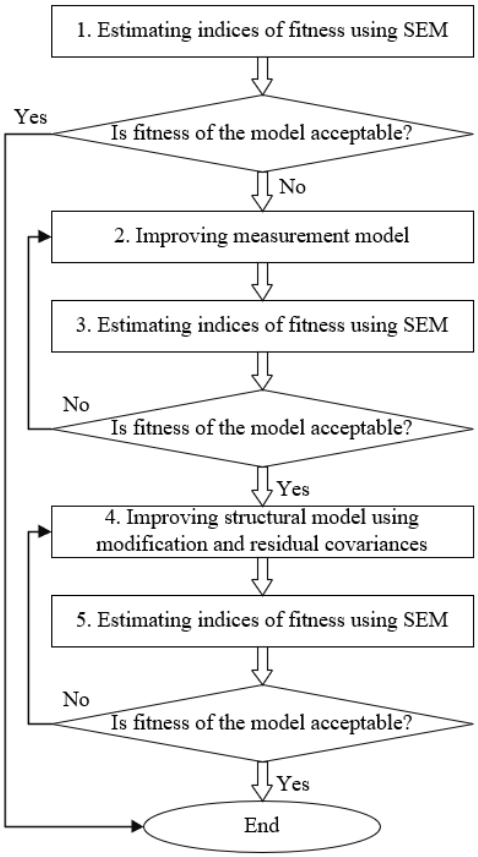

Fig. 5. Reliability Test.

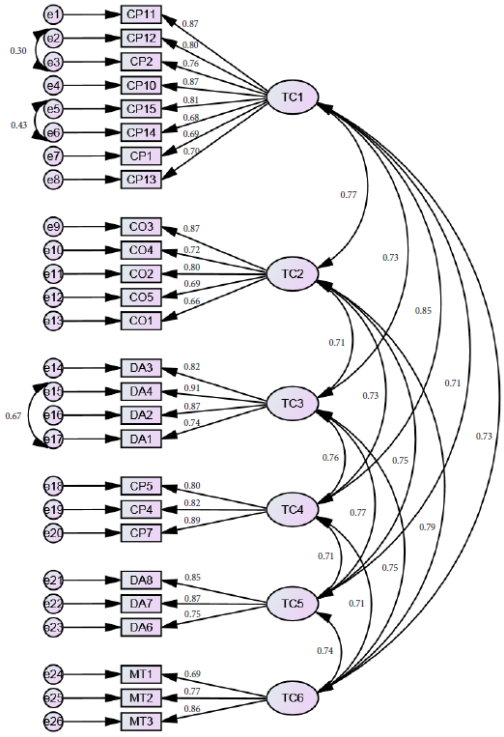

Fig. 6. Measurement model.

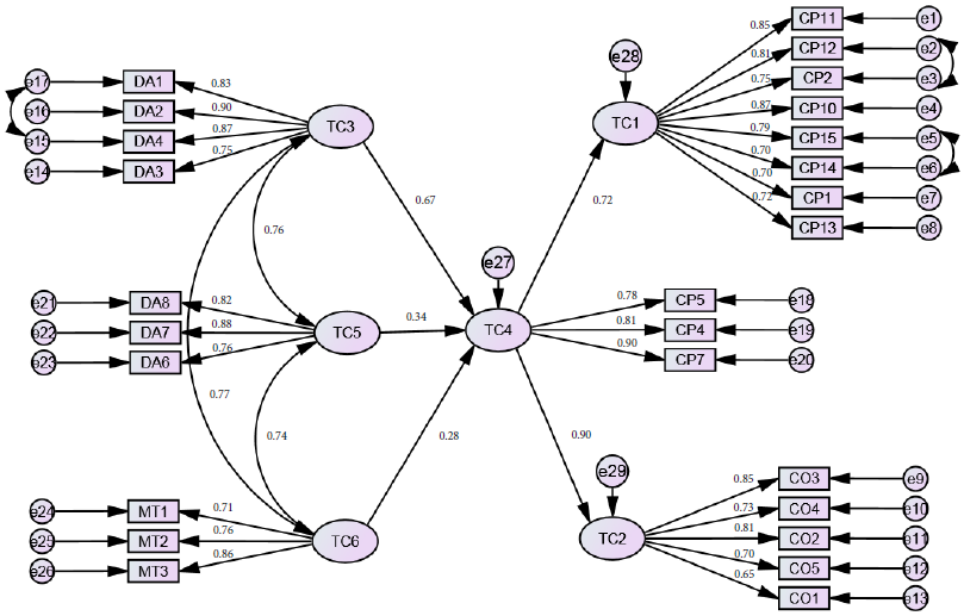

Fig. 7. The result of SEM analysis.

The H1 to H5 were assessed by examining the standardized direct effects, represented by the standardized path coefficients, along with the two-tailed significance level for each hypothetical path. Project characteristics exhibited the most substantial positive impact on Working ability ($\beta = 0.67$, $p < 0.001$), and Working ability demonstrated the most significant positive effect on Economic efficiency ($\beta = 0.90$, $p < 0.001$). The standardized path coefficients for hypotheses H1, H4, and H5 exceeded 0.50, denoting a significant impact, whereas the path coefficients for H2 was above 0.30, indicating a moderate influence..

Different professionals in the construction industry may participate in the process of selecting formwork systems (FWS). These individuals exhibit diverse perspectives and assessments concerning the importance assigned to criteria governing FWS selection. Nevertheless, there could be substantial statistical variances or discrepancies in the perceived significance levels of criteria for selecting formwork, which comes from perspective and cognitive among distinct group of construction professionals. Each group may have different priorities, requirements, and constraints, which must be considered in the decision-making process. However, previous research has predominantly utilized Multi-Criteria Decision-Making (MCDM) methodologies for shuttering preference selection, typically relying on the viewpoints of contractors or specific groups of individuals without research based on a meta-evaluation opinion. These studies commonly employed specific MCDM methods like AHP, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), etc., to assign relative weights to the criteria, overlooking the interrelationships among the groupings of shuttering selection criteria. In recent years, a prevalent and beneficial approach in the literature involves SEM with various MCDM methods to address specific selection and ranking challenges. The SEM approach employed in this study unveils quantitative direct and indirect effects, providing valuable insights. Construction professionals and practitioners can leverage these insights in MCDM methods by employing a combined SEM-MCDM approach to identify shuttering preference.

4. Conclusions

Selecting the appropriate shuttering solution for a high-rise building entails an intricate decision-making process that involves evaluating multiple criteria with differing priorities. Each project possesses unique design characteristics, scheduling plans, and construction technologies, making it challenging to identify a universal shuttering solution for all projects. This impetus led the authors to undertake surveys aimed at gathering empirical data derived from the perspectives of experts in the construction sector to create databases for in-depth analysis. The research has discovered latent factors influence on the choice of shuttering for construction projects in Vietnam, including: Labor productivity; Economic efficiency; Project characteristics; Working ability; Available equipment, Environmental conditions. Moreover, The Analytic Hierarchy Process is employed to choose shuttering options, drawing insights from expert interviews. Notably, the study brings forth plastic shuttering as an option in the comparative calculation model, a material not explored in previous studies. Following the analysis, the shuttering systems are ranked with advantages in the order of plastic shuttering, aluminium shuttering, timber shuttering. Many experts advocate for opting for plastic shuttering solutions in construction due to numerous advantages, including faster construction speed, low self-weight, minimal maintenance costs, and a smooth surface finish, etc. The outcomes derived from the AHP model have significantly contributed to offering unbiased assessments that mirror the current developmental aspirations of the construction industry.

The outcomes of this study can be employed to validate and compare previous research on shuttering selection criteria, both qualitatively and quantitatively. Moreover, engineers, contractors, and project managers can employ the identified quantitative relationships and interdependencies within the categories of criteria for selecting formwork, as revealed in this study, to assist in determining the most suitable formwork. The quantitative impacts among these criteria can be integrated into MCDM methodologies by implementing a unified SEM–MCDM technique. As a result, it is expected that this study will function as a valuable tool for construction professionals actively involved in the decision-making processes related to formwork selection, contributing to the success of projects.

The results obtained from this research furnishes stakeholders with an extensive and holistic insight into the facets of impact that require meticulous consideration during the selection, planning, and decision-making stages for the utilization of a shuttering system in construction projects. From there, contributing to improving understanding and supporting construction managers to plan effectively and improve knowledge related to the problem of choosing the right shuttering solution for each ongoing project. Thereby helping to control and improve project quality for stakeholders when participating in the project implementation process, while promoting the development of the construction industry.

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Conflicts of interest

The authors declare no conflict of interest.

Authors' contributions statement

The authors collectively composed the main manuscript, generated all figures and tables, and thoroughly reviewed the revisions prior to submission.

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